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ABSTRACT

This document is a summary of "Benchmarks for Science Literacy", which is a supporting document of "Science for All Americans" published by the American Association for Advancement of Science (AAAS) as part of Project 2061. "Benchmarks for Science Literacy" consists primarily of statements regarding what all students should know and be able to do in science, mathematics, and technology by the end of grades two, five, eight, and twelve. The purpose of this summary is to answer frequently asked questions about "Benchmarks for Science Literacy". The topics of these questions relate to curriculum reform, the nature of Project 2061 benchmarks, the scope of benchmarks, the developers of benchmarks, utilizing benchmarks, and sources of benchmarks. Question answers are accompanied by reproductions of pages from "Benchmarks for Science Literacy." (DDR)

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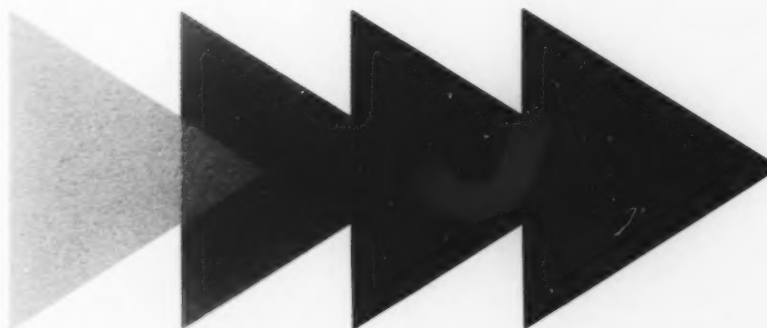
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BENCHMARKS

FOR SCIENCE LITERACY



AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

PROJECT 2061

SUMMARY

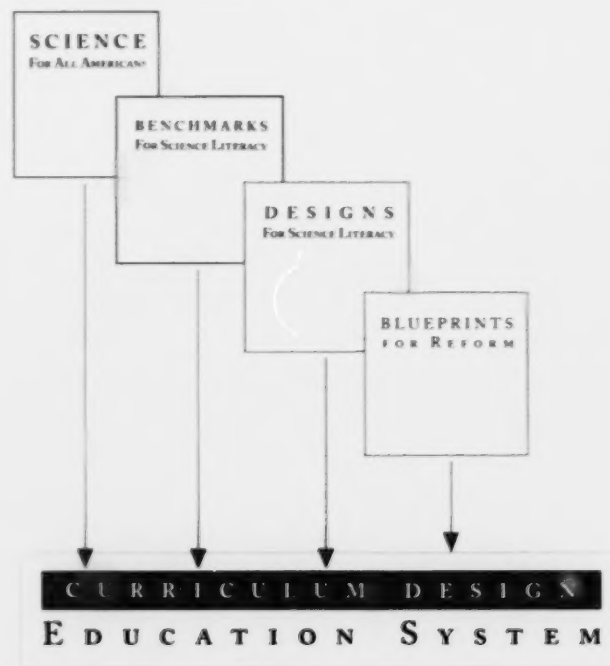


The American Association for the Advancement of Science (AAAS) is the leading federation of scientific societies in the world, with more than 141,000 individual members and nearly 300 affiliated scientific organizations and academies of science.

The American Association for the Advancement of Science wishes to express its gratitude to the major funders listed below and to the many other businesses, school districts, and individuals who contributed to Project 2061 and the work leading to this report. The opinions, findings, conclusions, and recommendations expressed in *Benchmarks for Science Literacy* are those of Project 2061 and do not necessarily reflect the views of these organizations.

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Project 2061 is a long-term initiative of the AAAS to reform K-12 education in natural and social science, mathematics, and technology. Begun in 1985, the Project is developing a set of tools to help curriculum reform on local, state, and national levels. *Science for All Americans*, has described what all students should know and be able to do by the time they leave high school. *Benchmarks for Science Literacy* specifies what student progress is reasonable to have been made by the end of grades 2, 5, 8, and 12. Other products of Project 2061 will provide principles for curriculum design, a resource database for curriculum and instruction, and blueprints for reforming other aspects of the education system.



■ SUMMARY BENCHMARKS FOR SCIENCE LITERACY

Science literacy – which embraces science, mathematics, and technology – has emerged as a central goal of education. Yet the fact is that general science literacy eludes us in the United States. A cascade of recent studies has made it abundantly clear that by both national standards and world norms, U.S. education is failing too many students – and hence failing the nation. By all accounts, America has no more urgent priority than the reform of education in science, mathematics and technology.

Reform is needed because the nation has not yet acted decisively enough in preparing young people, especially the minority children on whom the nation's future is coming to depend, for a world that continues to change radically in response to the rapid growth of scientific knowledge and technological power. But educational reform cannot simply be legislated. It will take time, determination, collaboration, resources, and leadership. It will take daring and experimentation. And it will take a shared national vision of what Americans want their schools to achieve.

Science for All Americans – initially published in 1989 – is intended to help in the formation of that vision. It has now been joined by another Project 2061 report, *Benchmarks for Science Literacy*, which consists primarily of statements of what all students should know and be able to do in science, mathematics, and technology by the end of grades 2, 5, 8, and 12. The grade demarcations suggest reasonable targets for curriculum design and checkpoints for estimating student progress toward the science literacy goals outlined in *Science for All Americans*.

The purpose of this summary is to answer questions that are frequently asked about *Benchmarks*. These are:

- Where does *Benchmarks for Science Literacy* stand with regard to curriculum reform?
- Just what are Project 2061 benchmarks?
- What ground does *Benchmarks* cover?
- Who developed the benchmarks?
- How can *Benchmarks* be used?
- Where can *Benchmarks* be obtained?

■ BENCHMARKS AND CURRICULUM REFORM

Benchmarks for Science Literacy is based on the following Project 2061 premises concerning curriculum reform:

- Literacy in science, mathematics, and technology helps people live interesting, responsible, and productive lives. In a culture increasingly pervaded by science, mathematics, and technology, science literacy requires understandings and habits of mind that enable citizens to grasp what those enterprises are up to, to make some sense of how the natural and designed worlds work, to think critically and independently, to recognize and weigh alternative explanations of events and design trade-offs, and to deal sensibly with problems that involve evidence, numbers, patterns, logical arguments, and uncertainties.
- Curriculum reform should be shaped by our vision of the *lasting* knowledge and skills we want students to acquire by the time they become adults. This ought to include both a common core of learning – the focus of Project 2061 – and learning that addresses the particular needs and interests of individual students.
- If we want students to learn science, mathematics, and technology well, we must radically reduce the sheer amount of material now being covered. The overstuffed curriculum places a premium on the ability to commit terms, algorithms, and generalizations to short-term memory and impedes the acquisition of understanding.
- Goals should be stated so as to reveal the intended character and sophistication of learning to be sought. Although goals for knowing and doing can be described separately, they should be learned together in many different contexts so that they can be used together in life outside of school.
- The common core of learning in science, mathematics, and technology should center on science literacy, not on an understanding of each of the separate disciplines. Moreover, the core studies should include connections among science, mathematics, and technology and between those areas and the arts and humanities and the vocational subjects.
- Common goals do not require uniform curricula, teaching methods, and materials. Project 2061 is developing tools to enable teachers to design learning experiences for students that take into account state and district requirements, student backgrounds and interests, teacher preferences, and the local environment.
- Reform must be comprehensive and long-term, if it is to be significant and lasting. It must center on *all* children, *all* grades, and *all* subjects. In addition, it must deal interactively with all aspects of the system – curriculum, teacher education, the organization of instruction, assessment, materials and technology, policy, and more.

Benchmarks is different from a curriculum, a curriculum framework, a curriculum design, or a plan for a curriculum. It is a tool to be used by educators in designing a curriculum that makes sense to them and meets the standards for science literacy recommended in *Science for All Americans*. Moreover, *Benchmarks* does not advocate any particular curriculum design. Far from pressing for one way of organizing instruction, Project 2061 pursues a reform strategy that will lead eventually to greater curriculum diversity than common today.

Benchmarks is a compendium of specific science literacy goals that can be organized however one chooses. As in most reference works, chapter order is unrelated to the relative importance of the benchmarks. Chapter 1 does not set the tone for all those that follow, nor does Chapter 12 culminate all that came before. Indeed, Project 2061 expects that benchmarks from the latter will appear in combination with those from various other chapters in most curriculum units that address science literacy goals. A version of *Benchmarks* on a computer disk enables users to assemble benchmarks from various chapters into cogent sets.

Benchmarks specifies thresholds rather than average or advanced performance. It describes levels of understanding and ability that *all* students are expected to reach on the way to becoming science literate. A well-designed curriculum will provide students with the help and encouragement they need to meet those standards.

Benchmarks concentrates on the common core of learning that contributes to the science literacy of all students. It does not spell out all of the science, mathematics, and technology goals that belong in the K-12 curriculum. Most students have interests, abilities, and ambitions that extend beyond the core studies, and some have learning difficulties that must be taken into account.

Benchmarks avoids technical language used for its own sake. The number of technical terms that most adults must understand is relatively small. Accordingly, the 12th-grade benchmarks use only those technical terms that ought to be in the vocabulary of science-literate people. The language in the benchmarks for earlier grades is intended to signal the nature and sophistication of understandings to be sought. The Project 2061 analysis of these and other issues is summarized in Chapter 14: Issues and Language.

Benchmarks sheds only partial light on how to achieve the goals it recommends. Deliberately. The means for realizing the ends listed in *Benchmarks* will be discussed in other Project 2061 materials. Although *Benchmarks* includes some commentary on aspects of instruction, that commentary is to clarify the meaning and intent of the benchmarks, not to present a systematic and detailed program of instruction.

Benchmarks is informed by research. Research on students' understanding and learning bears significantly on the selection and grade placement of the benchmarks. Project 2061 surveyed the relevant research literature in the English language (and some in other languages) in search of solid findings on which to base benchmark decisions. The findings are discussed in Chapter 15: Concerning the Research Base.

- **Benchmarks is a developing product.** It will undergo periodic updates as more research on learning becomes available and as users of *Benchmarks* report their experiences. One of the important responsibilities of the Project 2061 school-district sites is to suggest revisions of *Benchmarks* based on their analysis of ongoing research and user recommendations.
- **Benchmarks is but one of a family of tools being designed by Project 2061.** To help educators bring about fundamental, lasting reform, *Benchmarks* and *Science for All Americans* will be joined by other products. *Designs for Science Literacy* will describe Project 2061 models and curriculum blocks and will outline principles for configuring Project 2061 curricula. *Resources for Science Literacy* will be a continually updated database of outstanding learning and teaching materials suitable for curricula based on Project 2061 principles. *Blueprints for Systemic Reform* will recommend changes in the education system needed to make innovative K-12 curriculum reforms possible. A computerized curriculum-design and resource system is being developed to incorporate all of the Project 2061 products and link them interactively to each other and to educational resources.

- **Benchmarks is a companion for *Science for All Americans*, not a substitute.** *SFAA* presents a vision of science literacy goals for all students to reach by the time they finish the 12th grade, and *Benchmarks* maps out the territory that students will have to traverse to get there. *SFAA* emphasizes cogency and connectedness. *Benchmarks* emphasizes analysis of the *SFAA* story into components and their sequence. In grades 9-12, where building coherence and connections becomes the main task, no list of components would be adequate to represent science literacy. (Indeed, not all of the detailed ideas in *SFAA* are represented in *Benchmarks*.) At the 9-12 level, therefore, reference to *SFAA* is more than ever necessary for a complete picture of science literacy, which the 9-12 *Benchmarks* only approximate.

Benchmarks for Science Literacy is a report from a cross-section of practicing educators. Rather than assemble a national group that could meet only infrequently, Project 2061 decided, with the publication of *SFAA* in 1989, to form school-district teams so that the members of each would be close enough to discuss issues often and at length.

The various teams were chosen to be very different from one another by virtue of locale, demographics, and available resources, so that they might collectively represent the nation. The Project recruited teams of school teachers and administrators from six sites around the country – in rural Georgia; in suburban McFarland, Wisconsin; and in urban Philadelphia, San Antonio, San Diego, and San Francisco.

So that the teams could plan for 13 years of schooling in science, mathematics, and technology, team members were chosen to bring all grades and subjects to the process. Each team had 5 elementary teachers, 5 middle-school teachers, 10 high-school teachers, 1 principal from each level, and 2 curriculum specialists. The teachers had taught the life and physical science, social studies, mathematics, technology, and also other disciplines.

Each 25-member team received clerical support, computers and computer training, office space, reference materials, travel funds, and other resources they needed for research and development. The school districts involved agreed to release team members an average of four days per month from their classrooms to work on Project 2061 tasks. Faculty from local universities provided consultation and technical assistance to the teams as requested throughout the year. Consultants from around the country offered their expertise at annual summer conferences, where staff and teams met to advance mutual tasks.

By 1991 the teams had agreed among themselves that it was both possible and desirable to produce a common set of student

expectations for several grade levels – benchmarks. To support this effort, a thorough review was undertaken by the Project 2061 staff of the research literature on student learning of science, mathematics, and technology, and the findings were shared with the teams. A summary appears in *Benchmarks* Chapter 15: The Research Base. A common set of benchmarks was drafted by spring 1992, reviewed by the teams and consultants and revised accordingly. In early 1993, draft benchmarks were ready for the scrutiny of groups and individuals knowledgeable and concerned about science, mathematics, and technology education.

Reviews were solicited from scientific and educational organizations, which were encouraged to assemble review teams to debate and discuss the draft. Other reviews came from state curriculum groups, research and development centers, regional educational laboratories, the American Association for the Advancement of Science sections, consultants and affiliates from all phases of the Project, publishers, and individual scientists and educators in science, mathematics, and technology. Several states accepted the Project's invitation to set up teams to review the draft document.

All told, the Project received over 1,300 responses from groups and individuals throughout the country. Those responses came from 46 states; urban and rural school districts; elementary-, middle-, and high-school teachers; scientists and engineers from diverse disciplines; and groups traditionally under-represented in mathematics, science, and technology.

After a preliminary rewrite based on all the comments, leaders of the Project teams' review groups and consultants from mathematics, science, social studies, and technology education convened to discuss still-unresolved issues. Guided by the National Council on Science and Technology Education, the staff then completed the final version. Details on the entire process are given in Chapter 13: The Origin of Benchmarks.

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Project 2061 answers the question, "What should all students learn to become science literate?" at several levels of specificity. It asserts, at the most general level, that every student should leave school with a good grasp of how science works, a functional knowledge of some of the most important concepts and principles from science, mathematics, and technology, and a capacity for scientific ways of thinking.

At the next level, science literacy is defined in terms of some 65 sets of concepts and skills. These appear as sections within

Chapters 1 through 12 in both *Science for All Americans* and *Benchmarks for Science Literacy*. The table of contents for *Benchmarks* appears on pages 6 and 7.

But what exactly do we want students to learn about any one of those topics? *SFAA* answers with four to seven explanatory paragraphs for each topic and *Benchmarks* provides up to 15 benchmarks for each topic at each of four grade bands. On this page and the opposite page are half-size replicas of *Benchmarks* pages that show examples from different chapters.

THE LIVING ENVIRONMENT

Grade 1 through 2

Students should investigate the habitats of many different kinds of local plants and animals, including weeds, aquatic plants, insects, worms, and amphibians, and some of the ways in which animals depend on plants and on each other.

By the end of the 2nd grade, students should know that

- ▶ Animals eat plants or other animals for food and may also use plants (or even other animals) for shelter and nesting.
- ▶ Living things are found almost everywhere in the world. There are somewhat different kinds in different places.

Grade 3 through 5

Students should explore how various organisms satisfy their needs in the environments in which they are typically found. They can examine the survival needs of different organisms and consider how the conditions in particular habitats can limit what kinds of living things can survive. Their studies of interactions among organisms within an environment should start with relationships they can directly observe. By viewing nature films, students should see a great diversity of life in different habitats.

By the end of the 5th grade, students should know that

- ▶ For any particular environment, some kinds of plants and animals survive well, some survive less well, and some cannot survive at all.
- ▶ Insects and various other organisms depend on dead plant and animal material for food.
- ▶ Organisms interact with one another in various ways besides providing food. Many plants depend on animals for carrying their pollen to other plants or for dispersing their seeds.
- ▶ Changes in an organism's habitat are sometimes beneficial to it and sometimes harmful.
- ▶ Most microorganisms do not cause disease, and many are beneficial.

5D. INTERDEPENDENCE OF LIFE

Grade 6 through 8

As students build up a collection of cases based on their own studies of organisms, readings, and film presentations, they should be guided from specific examples of the interdependency of organisms to a more systematic view of the kinds of interactions that take place among organisms. But a necessary part of understanding complex relationships is to know what a fair proportion of the possibilities are. The full-blown concept of ecosystem (and that term) can best be left until students have many of the pieces ready to put in place. Prior knowledge of the relationships between organisms and the environment should be integrated with students' growing knowledge of the earth sciences.

By the end of the 8th grade, students should know that

- ▶ In all environments—freshwater, marine, forest, desert, grassland, mountain, and others—organisms with similar needs may compete with one another for resources, including food, space, water, air, and shelter. In any particular environment, the growth and survival of organisms depend on the physical conditions.
- ▶ Two types of organisms may interact with one another in several ways: They may be in a producer/consumer, predator/prey, or parasite/host relationship. Or one organism may scavenge or decompose another. Relationships may be competitive or mutually beneficial. Some species have become so adapted to each other that neither could survive without the other.

Grade 9 through 12

The concept of an ecosystem should bring coherence to the complex array of relationships among organisms and environments that students have encountered. Students' growing understanding of systems in general can suggest and reinforce characteristics of ecosystems—interdependence of parts, feedback, oscillation, inputs, and outputs. Stability and change in ecosystems can be considered in terms of variables such as population size, number and kinds of species, and productivity.

By the end of the 12th grade, students should know that

- ▶ Ecosystems can be reasonably stable over hundreds or thousands of years. As any population of organisms grows, it is held in check by one or more environmental factors: depletion of food or nesting sites, increased loss to increased numbers of predators, or parasites. If a disaster such as flood or fire occurs, the damaged ecosystem is likely to recover in stages that eventually result in a system similar to the original one.
- ▶ Like many complex systems, ecosystems tend to have cyclic fluctuations around a state of rough equilibrium. In the long run, however, ecosystems always change when climate changes or when one or more new species appear as a result of migration or local evolution.
- ▶ Human beings are part of the earth's ecosystems. Human activities can, deliberately or inadvertently, alter the equilibrium in ecosystems.

Sample pages 116 and 117 at the left illustrate the succession of benchmarks for a single topic, Interdependence of Life, and show how expectations for students increase over 13 years of schooling. Notice, for example, that as one follows the first benchmark in each grade range from K-2 to 9-12, the concept of ecosystems grows progressively.

Whereas the benchmarks in the previous example propose knowledge to be acquired, those in the two sample pages below recommend skills to be acquired. Both are from Chapter 12: Habits of Mind – page 293 from the section Computation and Estimation, page 299 from the section Critical-Response Skills.

12. MEASUREMENT AND ESTIMATION

Grade 2 through 5

By the end of the 2nd grade, students should be able to

- Use hammers, screwdrivers, clamps, rulers, scissors, and hand lenses, and operate ordinary audio equipment.
- Assemble, describe, take apart and reassemble constructions using interlocking blocks, Erector sets, and the like.
- Make something out of paper, cardboard, wood, plastic, metal, or existing objects that can actually be used to perform a task.
- Determine the linear dimensions in whole units of objects having straight edges.

By the end of the 5th grade, students should be able to

- Choose appropriate common materials for making simple mechanical constructions and repairing things.
- Measure and mix dry and liquid materials (in the kitchen, garage, or laboratory) in prescribed amounts, exercising reasonable safety.
- Keep a notebook that describes observations made, carefully distinguishes actual observations from ideas and speculations about what was observed, and is understandable weeks or months later.
- Use calculators to determine area and volume from linear dimensions, aggregate amounts of area, volume, weight, time, and cost, and find the difference between two quantities of anything.
- Make safe electrical connections with various plugs, sockets, and terminals.

BENCHMARK FOR GRADES 2 THROUGH 5

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12. CRITICAL-RESPONSE SKILLS

Grade 3 through 6

By the end of the 5th grade, students should

- Buttress their statements with facts found in books, articles, and databases, and identify the sources used and expect others to do the same.
- Recognize when comparisons might not be fair because some conditions are not kept the same.
- Seek better reasons for believing something than "Everybody knows that..." or "I just know" and discount such reasons when given by others.

By the end of the 8th grade, students should

- Question claims based on vague attributions (such as "Leading doctors say...") or on statements made by celebrities or others outside the area of their particular expertise.
- Compare consumer products and consider reasonable personal trade-offs among them on the basis of features—performance, durability, and cost.
- Be skeptical of arguments based on very small samples of data, biased samples, or samples for which there was no control sample.
- Be aware that there may be more than one good way to interpret a given set of findings.
- Notice and criticize the reasoning in arguments in which (1) fact and opinion are intermingled or the conclusions do not follow logically from the evidence given, (2) an analogy is not apt, (3) no mention is made of whether the control groups are very much like the experimental group, or (4) all members of a group (such as teenagers or chemists) are implied to have nearly identical characteristics that differ from those of other groups.

BENCHMARK FOR GRADES 3 THROUGH 8

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Project 2061 places considerable emphasis on the interconnectedness of knowledge. To encourage curriculum designers to build important connections into units and materials, *Benchmarks* calls attention to possibilities both within and between chapters. Sample page 181 shows how this is done at the beginning of Chapter 8 in an introductory essay.

Sample page 267 below shows the introductory essay to the Models section of Chapter 11: Common Themes and an ALSO SEE box of cross-references to related chapters and sections.

Chapter 8 THE DESIGNED WORLD

- A AGRICULTURE
- B MATERIALS AND MANUFACTURING
- C ENERGY SOURCES AND USE
- D COMMUNICATION
- E INFORMATION PROCESSING
- F HEALTH TECHNOLOGY

The world we live in has been shaped in many important ways by human action. We have created technological options to prevent, eliminate, or lessen threats to life and the environment and to fulfill social needs. We have dammed rivers and cleared forests, made new materials and machines, covered vast areas with cities and highways, and decided—sometimes willy-nilly—the fate of many other living things.

In a sense, then, many parts of our world are designed—shaped and controlled, largely through the use of technology—in light of what we take our interests to be. We have brought the earth to a point where our future well-being will depend heavily on how we develop and use and restrain technology. In turn, that will depend heavily on how well we understand the workings of technology and the social, cultural, economic, and ecological systems within which we live.

SCIENCE FOR ALL AMERICANS

Here the focus is on particular technological systems, such as agriculture and manufacturing, and the benchmarks indicate what particular engineering, scientific, social, and historical understandings students should gain. In the companion Chapter 3: The Nature of Technology, the benchmarks deal with general principles of technology and engineering, with the relationships between technology and science, and with the effects of technology on society.

The sections in this chapter are not intended to cover all major areas of technology. Other areas—such as the technology of warfare, transportation, or architecture—might also have been included. The areas covered here should supply an ample sampling of major ideas to serve as a basis for understanding various key technologies of today—and those that will come tomorrow. For many of the ideas in this chapter, students will need a background understanding of the physical setting and the living environment, for which benchmarks are given in Chapter 4: The Physical Setting and Chapter 5: The Living Environment.

BENCHMARKS FOR SCIENCE LITERACY

11. MODELS

Physical, mathematical, and conceptual models are tools for learning about the things they are meant to resemble. Physical models are by far the most obvious to young children, as they should be used to introduce the idea of models. Dolls, stuffed animals, toy cars and airplanes, and other everyday objects can stimulate discussions about how those things are like and unlike the real things. The term *model* should probably be used to refer only to physical models in the early grades, but the notion of likeness will be the central issue in using any kind of model.

The usefulness of conceptual models depends on the ability of people to imagine that something they do not understand is in some way like something that they do understand. Imagery, metaphor, and analogy are every bit as much a part of science as deductive logic, and as much at home in science as in the arts and humanities. Students cannot be expected to become adept in the use of conceptual models, however, until they get to know quite a bit about materials, things, and processes in the accessible world around them through direct, hands-on experience. The curriculum emphasis, therefore, should be on a rich variety of experiences, not on generalizations about conceptual models. Moreover, students need to acquire images and understandings that come from drawing, painting, sculpting, playing music, acting in plays, listening to and telling stories, reading, participating in games and sports, doing work, and living life.

By their nature, mathematical models are usually more abstract than physical and conceptual models. The connection of mathematics to concrete matters, and hence its value for modeling, could be substantially stronger if mathematics were often taught as part of science, social studies, technology, health, gym, music, and other subjects, rather than only during "mathematics time." One of the drawbacks of teaching mathematics entirely as a separate subject is that mathematics is taught before real-world problems are identified, so the related exercises may have mostly to do with learning the procedures rather than with solving interesting problems.

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- Chapter 1 A SCIENTIFIC INQUIRY
2 A MATHEMATICAL, SCIENCE, AND TECHNOLOGY (modeling systems)
3 A MATHEMATICAL INQUIRY (mathematical modeling)
3 B DESIGN AND SYSTEMS
4 A THE UNIVERSE
5 D STRUCTURE OF MATTER
5 E INTERDEPENDENCE OF LIFE (modeling natural selection)
7 E PHYSICAL AND ENGINEERING SYSTEMS (modeling economic systems)
8 E INFORMATION PROCESSING (computer modeling)
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12 A CRITICAL REASONING SKILLS (integration of all subjects)

BENCHMARKS FOR SCIENCE LITERACY

Most sections of *Benchmarks* also have references to Research Notes found in Chapter 15: The Research Base. On the example page 66 below, the reference indicates that a summary of relevant research background begins on page 335. References to the research literature that are cited in these research notes are listed at the end of Chapter 15.

THE PHYSICAL SETTING

4 THE EARTH

An integrated picture of the earth has to develop over many years, with some concepts being visited over and over again in new contexts and greater detail. Some aspects can be learned in science, others in geography; some parts can be purely descriptive, others must draw on physical principles. The benchmarks in this section complement those of the previous section that locate the earth in the cosmos and those of the following section that focus on the surface of the earth. This arrangement does not imply any particular order of teaching. Often, teaching near-at-hand phenomena before teaching the far-distant ones makes sense; on the other hand, sometimes the near-to-far progression that makes sense

cognitively may not correspond to what interests children.

Perhaps the most important reason for students to study the earth repeatedly is that they take years to acquire the knowledge that they need to complete the picture. The full picture requires the introduction of such concepts as temperature, the water cycle, gravitation, states of matter, chemical concentration, and energy transfer. Understanding of these concepts grows slowly as children mature and encounter them in different contexts.

The benchmarks here call for students to be able to explain two phenomena—the seasons and the phases of the moon—that are usually not learned well. Most adults are unable to give even approximately correct explanations for them. Most students are *told* by teachers what causes the seasons and the phases of the moon, and they read about them without understanding. Moon phases are difficult because of students' unfamiliarity with the geometry of light and "seeing." To help figure out the geometry, students can act out the sun-earth-moon relationships and make physical models. In trying to understand the seasons, students have difficulties regarding geometry and solar radiation. Students need direct experience with light and surfaces—shadows, reflection, and warming effects at different angles.

RESEARCH NOTES page 335

- Chapter 3
- 1. DESIGN AND SYSTEMS (designs made with knowledge)
 - 2. INTERDEPENDENCE IN TIME (climate and habitats)
 - 3. FORM OF MATTER AND ENERGY (exchange with physical environment)
 - 4. GEOMETRIC INTERDEPENDENCE (geographic influences)
 - 5. AEROSOL FORM (climate and resources)
 - 6. MATERIALS AND MATERIALS CHANGING (effects on resources)
 - 7. ENERGY SOURCES AND USE (effects on resources)
 - 8. DESCRIBING THE EARTH FROM THE CENTER OF THE UNIVERSE
 - 9. EXPLORING TIME (history of the earth)
 - 10. THE EARTH
 - 11. CHANGING AND CHANGING
 - 12. SPACE

is to oneself and voluntary, it is considered a part of life and hardly worthy of concern by others. In the second perspective, if the risk of failure involves harm to oneself and benefits to others, then it is of primary interest. Harm to others is simply ignored in this perspective (Fleming, 1986a, 1986b).

1C ISSUES IN TECHNOLOGY

Some high-school students believe scientists and engineers are more capable of making decisions about public issues related to science and technology than the general public. Students believe that scientists and engineers know all the facts and are not influenced by personal motives and interests (Fleming, 1987; Aikenhead 1987).

4 THE PHYSICAL SETTING

There is more research on student conceptions about The Physical Setting than in any other area. The Pfundt and Duit (1991) bibliography reveals that more than 70% of the published papers about students' conceptions in science were concerned with topics related to The Physical Setting benchmarks. Much research has focused on topics related to The Earth, Structure of Matter, Energy Transformations, and Motion. Topics related to The Universe and Forces of Nature have also received attention, but for the Processes That Shape the Earth, there is little research. Even in the frequently researched areas, relatively few studies report on long-term teaching interventions that try to improve students' ideas about the physical setting. The available literature on students' understanding of topics related to The Physical Setting has been reviewed in Driver, Guesne, & Tiberghien (1985). Conference proceedings on these topics include Driver & Milar (1985), Duit, Goldberg, & Niedderer (1992), Jung, Pfundt, & Rhoensck (1981), Lajne (1985), and Lajne et al., (1990).

4A THE UNIVERSE

Research available on student understanding about The Universe focuses on their conceptions of the sun as a star and as the center of our planetary system. The ideas "the sun is a star" and "the earth orbits the sun" appear counter-intuitive to elementary-school students (Baxter, 1989; Voniadiou & Brewer, 1992) and are not likely to be believed or even understood in those grades (Voniadiou, 1991). Whether it is possible for elementary students to understand these concepts even with good teaching needs further investigation.

4B THE EARTH

Shape of the earth. Student ideas about the shape of the earth are closely related to their ideas about gravity and the direction of "down" (Nussbaum, 1985a; Voniadiou, 1991). Students cannot accept that gravity is center-directed if they do not know the earth is spherical. Nor can they believe in a spherical earth without some knowledge of gravity to account for why people on the "bottom" do not fall off. Students are likely to say many things that sound right even though their ideas may be very far off base. For example, they may say that the earth is spherical but believe that people live on a flat place on top or inside of it—or believe that the round earth is "up there" like other planets, while people live down here (Snieder & Pulos, 1983; Voniadiou, 1991). Research suggests teaching the concepts of spherical earth, space, and gravity in close connection to each other (Voniadiou, 1991). Some research indicates that students can understand basic concepts of the shape of the earth and gravity by 5th grade if the students' ideas are directly discussed and corrected in the classroom (Nussbaum, 1985a).

Explanations of astronomical phenomena. Explanations of the day-night cycle, the phases of the moon, and the seasons are very challenging for students. To understand these phenomena, students should first

■ USING BENCHMARKS

Benchmarks was prepared as a tool to be used, along with *Science for All Americans*, by everyone engaged in state or local efforts to transform learning in science, mathematics, and technology. The following suggestions for using *Benchmarks* came from Project 2061 team members, consultants, and staff, and from individuals who have seen prepublication draft versions of *Benchmarks*:

- Study groups of teachers, administrators, school-board members, parents, interested citizens, and, whenever possible, scientists, engineers, and mathematicians can use *Benchmarks* to explore the concept of science literacy in relation to instruction in the early elementary, upper elementary, middle-, and high-school grades.
- Cross-grade, cross-subject committees of teachers and curriculum specialists can use *Benchmarks* to gauge how well a K-12 curriculum or curriculum framework (state or local) addresses education for science literacy. Such an analysis can also lead to suggestions for making immediate and long-term curriculum and course improvements.
- Developers of instructional materials can use *Benchmarks* to guide the creation of materials to support the work of teachers who are trying to foster science literacy for all students. Similarly, test writers can use *Benchmarks* to develop grade-level materials and techniques for assessing student progress toward science literacy.

- Other reform efforts may find *Benchmarks* useful in supporting their work, just as Project 2061 has relied on so many of them for ideas and information. The federal programs that drew heavily on *Science for All Americans*, such as the Statewide Systemic Initiatives (National Science Foundation), the Eisenhower Science and Mathematics Initiative (Department of Education), and the National Assessment of Educational Progress, have indicated that they intend also to use *Benchmarks*.
- Universities and colleges that prepare elementary and secondary school teachers can use *Benchmarks* to supplement *SFAA*. Whereas *SFAA* explores the concept of science literacy in general, *Benchmarks* raises issues closer to the realities of curriculum and instruction.
- Researchers can use *Benchmarks* to identify important topics for investigation. Such topics might include studies on the appropriate grade-level placement of benchmarks, the relationship between benchmarks and their prerequisites, effective ways to group benchmarks into instructional units, how to assess student progress toward science literacy, and how to evaluate learning materials and techniques used in support of the benchmarks.



PROJECT 2061 school district teams at first summer, 1989

■ OBTAINING BENCHMARKS

Benchmarks for Science Literacy, *Benchmarks for Science Literacy on Disk* and *Science for All Americans* are published by Oxford University Press. They can be ordered by mail or telephone from Oxford University Press
198 Madison Avenue
New York, NY 10016-4314
1-800-451-7556

For information on discount prices for bulk purchases, contact the phone number at left.

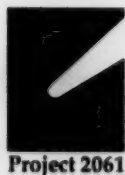
Copies can also be purchased at many university book stores and at the national and regional conventions of the National Science Teachers Association.



■ *The terms and circumstances of human existence can be expected to change radically during the next human lifespan. Science, mathematics, and technology will be at the center of that change — causing it, shaping it, responding to it. They will therefore be essential to the education of today's children for tomorrow's world. What should the substance and character of such education be?*

■ **PROJECT 2061** — begun in 1985, the year Halley's Comet was last here — is a long-term effort of scientists and educators on behalf of *all* children. Its purpose is to help transform the nation's school system so that all students become well educated in science, mathematics, and technology.

■ Today's young people will, as adults, greatly influence what life on earth will be like in 2061, the year Halley's Comet next returns. Being literate in science is a condition for doing so responsibly, as well as for living a full and interesting life. **BENCHMARKS FOR SCIENCE LITERACY** and its companion publication, **SCIENCE FOR ALL AMERICANS**, contribute to that end.



Project 2061

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